Design, Machining and Installation Manual

TENMAT

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INTRODUCTION

TENMAT FEROFORM MARINE BEARINGS are used in many diverse application areas across all vessel types. The UNIVERSAL nature of the material means that one basic grade (T14) can be used with all manner of fluids from clean water through to heavily abrasive laden conditions, for greases/oils through to various fuels and chemicals. For dry self lubricating bearing applications or where dry start up or indeed where lubrication starvation may be encountered, or where noise free running is a pre-requisite, then graphite (T11) or molybdenum disulphide (T12) containing grades are available to cater for these special needs.

These advanced HIGHLY TECHNOLOGICAL composites are setting new standards of wear resistance, versatility and reliability for marine bearings and are thus able to offer the Ship Owner, Operator, Shipyard and Naval Architect a number of substantial cost savings.

This manual gives details of the Design Criteria, Machining Data and Fitting Instructions for FEROFORM Marine Bearings and bushes in all application areas including propeller shafts, rudders, stabilisers, pumps, general deck equipment such as winches, windlasses, davits, fair leads, cargo handling equipment and hatch covers and also for off-shore/ dockside applications.

Our experienced Technical Services Department are available to discuss and advise on all aspects of Marine Bearing use. Please Telephone [+44] (0)161 872 2181.
Alternatively, Fax [+44] (0)161 872 7596 for assistance.

IMPORTANT NOTICE

Tenmat welcomes the use of this manual or the associated C.D. ROM. However, any copies of the document must be transposed in its entirety, including this notice. No partial copy amendments are authorised without the express written permission of Tenmat Ltd.

The information offered in this document is only relevant to Tenmat Ltd. products or materials and is only offered to assist engineers in the overall deisgn of marine stern tube and rudder bearings. The information herein is presented in good faith but Tenmat does not warrant the conformity of its materials to the listed properties or the suitability of its materials for any particular purpose. Therefore, the final design of the bearing / system must be the responsibility of the appropriate approval society, shipyard, ship-owner or architect.

APPLICATIONS

FEROFORM Marine Bearings exhibit a versatility of applicational use unsurpassed by any other materials. This is made possible by the very wide range of physical, chemical and mechanical properties inherent in FEROFORM.

FEROFORM's major attributes are:

Resistance to abrasive conditions
High mechanical strength
Wide operational temperature range
Low friction
No stick slip
Resistance to shock loads
Very low water swell
No oil swell
High PV limit dry
Can be lubricated by any compatible fluid
(oil, water, grease etc)
Excellent chemical resistance

As a consequence of this unique versatility FEROFORM Marine Bearings have been successfully used in a very wide range of applications including:

Hull structure:

Propeller shaft - stern tubes and brackets
Rudders - all types
Stabilisers
Bow thrusters
CP Propeller e.g. pitch adjustment slides

Deck equipment:

Hatch covers - bearings and slide pads
Winches and Windlasses
Fairleads
Davits
Stern rollers
Ro-Ro ramps and doors

Other ship borne equipment:

Pumps
Cargo handling e.g. expansion pads, container handing & Cable laying equipment

Other Naval applications:

Submarines - hydroplane
mast bearings e.g. periscope, communications mast

LUBRICATION

Any compatible fluid can be used to lubricate FEROFORM bearings. Generally water, oil or grease is used the choice being dependent on whether the system is open or closed, and the speed of operation.

Under certain circumstances FEROFORM T11 or T12 grades can be used without lubrication e.g. where speed is so low as to not generate any significant heat.

It is strongly recommended that wherever an unlubricated application is considered our Technical Department is consulted in order that combined pressure and velocity effects (PV limits) can be evaluated.

WATER

Water is commonly used with FEROFORM T14 grade propeller shaft, impeller, pump, stabiliser and lower rudder bearings.

For high speed, full rotation applications (e.g. propeller shaft) it is generally preferred to have a positive water flow. Rotational speed generates heat and being such a good cooling medium, water is an ideal lubricant in these conditions.

The flow rate should be high enough to fully dissipate any heat produced by the rotational speed.

A minimum flow rate of 0.15 litres per minute per mm of shaft diameter is recommended.

This flow rate is good for all speeds and does not have to be increased for high rotational speeds. This is because at high speed, hydrodynamic lubrication films are formed significantly decreasing friction and therefore reducing heat generation.

Water lubrication systems are normally of the open type i.e. no aft seal.

Water should be supplied at the innermost point of the bearing line.

Since FEROFORM has high temperature resistance and does not suffer from hydrolysis, engine cooling water may be used to lubricate the stern tube bearings.

L:D ratios and groove configurations are described fully in section entitled “Dimensions”.

OIL

Commonly used as lubricant in stern tubes. Oil is normally considered to be a better lubricant than water but not such a good coolant.

Also, oil must be used in a closed system (fully sealed). Systems traditionally used with white metal bearings are perfectly satisfactory for use with FEROFORM bearings.

Such systems include:

a) Gravity flow from header tank through stern tube to drain tank. The oil is then normally pumped back to the header tank perhaps via a cooler.

b) Thermally induced flow where the stern tube is often kept cool by flooding the after peak.

c) Full circulation by pump.

Generally any SAE30 marine quality stern tube oil is acceptable, However, in a closed, oil lubricated system it is not normal practice to use corrosion resistant (stainless) materials. Therefore it is recommended that an emulsifiable oil is used so that in the event of water ingress, no free water will exist in the system thereby preventing potential corrosion.

Vickers Hydrox 550 oil is an acceptable example of such an emulsifiable oil.

Flow rates in the order of 0.01 litres per minute per mm of shaft diameter have been recorded.

NOTE:

THERE ARE TWO VERY SIGNIFICANT SAFETY FACTORS ASSOCIATED WITH USING FEROFORM IN THE EVENT OF (CATASTROPHIC) SEAL FAILURE:-

1. FEROFORM IS FULLY APPROVED TO OPERATE WITH WATER LUBRICATION AND EVEN IF THE SYSTEM UTILISES NON-CORROSION RESISTANT MATERIALS WATER CAN BE SAFELY USED TO REACH PORT.

2. POLLUTION PROBLEMS ARE RESTRICTED SINCE THE OIL SUPPLY CAN BE SHUT OFF AND WATER INJECTED INTO THE SYSTEM INSTEAD.

GREASE

Grease will not readily flow and hence does not offer any cooling effect.

Grease is therefore normally used where heat generation is not significant - namely very slow rotation or oscillatory motion as in a rudder application.

Also where bearings are used fairly infrequently, such as hatch covers, grease is a good choice of lubricant since it protects metallic parts from corrosion.

Warning Ref Grease

Please note that we can assume due to load and speed, heat would be generated in a stern tube application. This should be taken as a WARNING against the use of grease in this application. However, we do have society approvals happy with the concept and designs. This is a warning only for stern tube, therefore excluding the rudder application.

SEALS

Experience has shown that all approved seals can be used in conjunction with TENMAT's FEROFORM bearings.

No special requirements are necessary; fitting and operation should be in accordance with the seal manufacturer's recommendations.

PV LIMITS

PV need only be considered when heat is likely to be produced and not dissipated by the lubrication medium.

i.e. For an open, water lubricated system, assuming a flow rate of 0.15 litres per minute per mm of shaft diameter is used, there would be no need to consider PV since the water flow will more than adequately dissipate any heat produced.

As water has a very good cooling effect on the bearing, PV values well in excess of 1000 kg/cm^2 m/min are achievable for propeller shaft bearings. In fact 2000 PV would be well within the capability of FEROFORM `T' grades under hydrodynamic conditions.

For an oil lubricated system if the PV exceeds 275 MPa m/min then use of oil coolers in the system may be necessary. Please consult our Technical Department for advice.

See also table "Guide to Limiting PV Value" in section entitled GRADE SELECTION.

FRICTION

Extensive friction data is available in dry, wet or oil lubricated conditions. Should friction levels with any of these particular media be required please consult TENMAT Limited.

Values down to 0.01 have been recorded where hydrodynamic lubrication conditions exist.

GRADE SELECTION

All FEROFORM Marine grades are non-asbestos synthetic fibres impregnated with phenolic resins.

FEROFORM T14

The universal grade for fluid lubricated conditions. Therefore in most marine applications T14 is acceptable since lubrication will be present as oil, grease, water or the chemical being handled. For the rudder application the latest 10 MPa high pressure approval by leading societies gives further bonuses.

FEROFORM T11

The matrix additionally incorporates evenly dispersed graphitic filler. T11 can be used with water lubrication particularly where slow operational speeds are frequently used resulting in boundary lubrication conditions prevailing.

This grade can also operate dry (unlubricated) providing low frictional and high load carrying attributes up to a PV limit of 120 kg/cm^2 m/min.

FEROFORM T12

Grade T12 incorporates molybdenum disulphide evenly dispersed throughout the matrix to give low friction at high pressure even when used dry.

For applications requiring low stick- slip, low noise and/or dry start-up T12 is often specified e.g. by military users. Used where electrolytic corrosion could be a problem e.g. with graphited materials.

For dry running a PV limit of 140 kg/cm^2 m/min should be adhered to.

NOTE

All `T' grades are fully approved by the leading Classification Societies for

Propeller Shaft Applications -	water lubricated - open system. oil lubricated - closed system
Rudders - all types -	water, grease or oil lubricated

FEROFORM F36

F36 is a grade specially developed for bearing and wearing applications at elevated temperatures - up to 200°C. It utilises a high temperature phenolic resin encapsulating aramid composite textile reinforcement.

FEROFORM F363

As F36 but additionally incorporating graphite to provide low friction at high pressure and elevated temperature.

F36 and F363 also exhibit higher working pressure capability - 85 MPa (12320 lbf/in^2) and 75 MPa (10900 lbf/in^2) respectively.

Used in marine equipment requiring combination of high pressure, high temperature and low friction.

GUIDE TO LIMITING PV VALUE (Table 1)

Material Type	Dry Rubbing	Oil Impregnated (SAE 30 Oil)	Regular Grease Re-lubrication (Grade 2 Lithium)
T14	390 (18,213)	780 (72,852)	300 (14,000)
T11	410 (18500)	240 (11,200)	360 (16,800)
T12	420 (19,590)	260 (12,130)	380 (17,730)
F36	800	1,200	16,000
F363	1,000	1,500	2,000

PV values quoted are in kg/cm^2 m/min (lbf/in^2 ft/min) and derived from work done on mild steel shafts - EN3B with 0.8 µmRa surface finish.

BEARING CONFIGURATION

All traditionally used configurations can be utilised either in a fully machined, ready-to-fit form, or semi-finished for final machining by the shipyard.

Where dimensions of the shaft and housing are pre-known e.g. new ship build, bearings can be supplied fully finished but where shafts or housings may be re-worked to re-sleeve or clean off corrosion, for example, then semi-finished bearings should be ordered and final dimensioning/machining carried out by the shipyard once shaft and housing diameters are confirmed.

Full (Cylindrical) Bearings

This is generally the recommended configuration to use since machining, fitting and retention are all made easier by dealing with only one piece.

For example:

Machining is basically just two operations - OD and ID.
Retention can be by a simple interference fit.
Fitting can be carried out by freeze fitting.

This is the most commonly used configuration for rudder and propeller shaft bearings.

Whilst FEROFORM `T' grade tubes are manufactured in 1200mm lengths, for ease of handling and machining it may be preferred to use 600mm length pieces.

Split Bearings

Sometimes used where a need exists to be able to change a bearing without removing the shaft.

In such cases either mechanical methods of retention are used or if an interference fit is used a method has to be used whereby the interference can be broken mechanically. This can be accomplished by use of for example tapered keys.

If a bush is split by milling, shims are normally used to fill the gap left by the cut. It is however possible to produce a split bush with no gap by splitting a semi-finished tube (having say 3-5mm oversize and undersize on OD and ID respectively), lightly bonding the two halves back together using say an anaerobic adhesive and mechanical strapping, machining OD and ID in the normal way and then breaking the bond.

Such split bushes can, if required, be retained by normal interference fit.

Flanged Bearings (Split or Full Cylindrical)

May be used where either the flange is utilised as a method of location/mechanical retention or where a light axial load has to be accommodated.

NB High axial loads should be accommodated by a separate thrust ring and this would generally be a less expensive method to employ unless the flange were needed for location/retention/ removal consideration.

Stave Construction

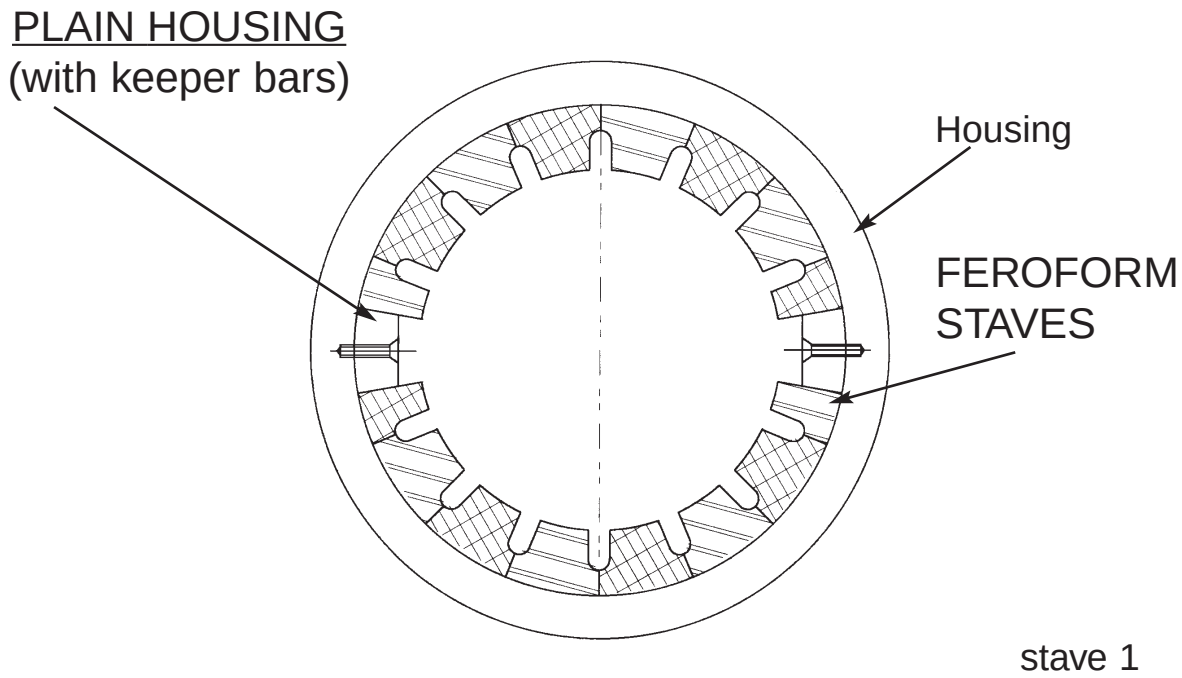
Stave construction of a bearing was originally developed when hard maple (lignum-vitae) was a popular choice for bearing material. In order to utilise as much of the tree as possible bearings were made up of a series of pieces (i.e. staves).

The side angles are such as to enable the staves to be laid up alongside each other to form a complete bearing. Often longitudinal keeper strips are additionally used say at 9 o'clock and 3 o'clock positions to facilitate fitting and retention.

A variation of this is to use a dovetailed housing (i.e. slotted housing).

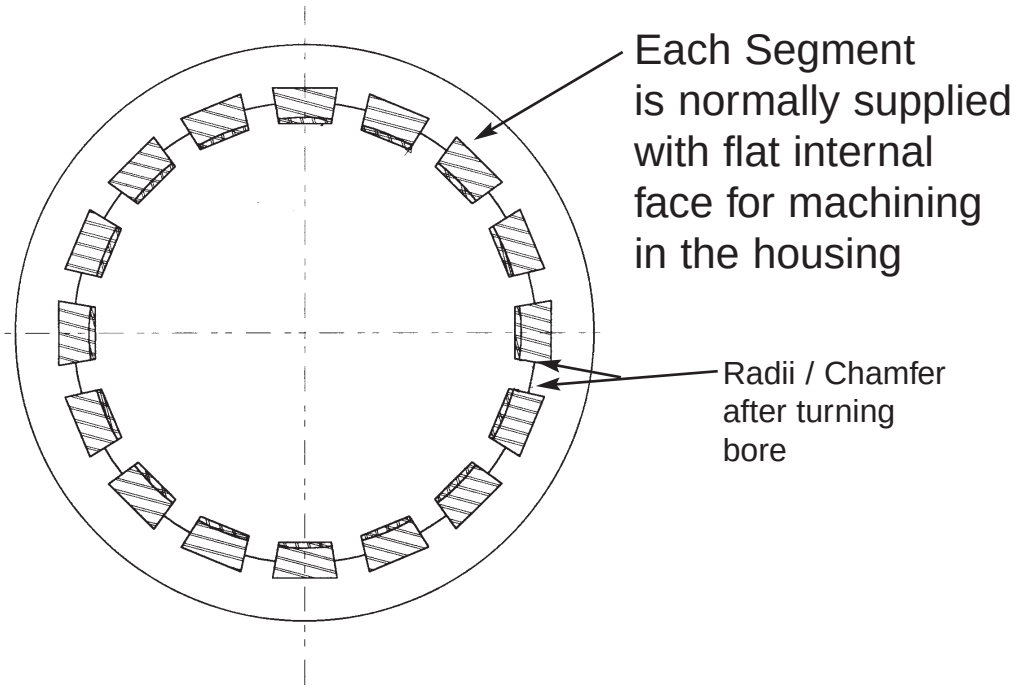
After installation of the staves they should be line bored to the correct inside diameter.

Some owners and shipyards retain a preference for this configuration and FEROFORM `T' grades can be supplied ready to use or in sheet form from which staves can be cut and machined.



stave 1

DOVETAILED HOUSING



STANDARD AVAILABLE FORMS

Tubes

Except for new build and OEM use where bearings can be supplied machined-to-drawing bearings are normally supplied semi-finished for final machining by the shipyard or repairer.

FEROFORM tubes are available to suit shaft diameters of 20mm to 1200mm (or larger on request). Tubes are of 1200mm standard maximum length but can be supplied as 900mm lengths to be more cost effective particulaly in urgent ship repair.

A standard size list is available.

Sheet

Standard sheet size is 1220mm x 1220mm in a range of thicknesses from 1.6mm to 75mm. (Thicker by request).

Staves

Available as required.

Some distributors keep a stock of some sizes.

SHAFT MATERIAL CHOICE

All traditionally used bearing shaft materials can be used with FEROFORM bearings.

It is generally accepted that the harder the shaft (or liner/ sleeve) material, the better its wear resistance will be against almost any bearing material. This is particularly true for abrasive conditions in water lubricated systems.

Bronze

Strictly speaking bronze is an alloy of copper with tin but the word has become synonymous with a superior material compared to brass.

Hence materials such as silicon bronze and aluminium bronze contain no tin.

The “bronzes” commonly used in marine applications are

1. Phosphor bronze.
2. Admiralty gunmetal.
3. Nickel aluminium bronze
4. Copper Nickel

Generally bronze shaft liners give good performance against FEROFORM bearings but although offering resistance to sea water and corrosion, easy machining and being non-magnetic bronzes should not be used where operating continuously in abrasive conditions; here a harder shaft liner should be used.

Steels

When carbon is alloyed with iron, the hardness and strength of the metal first increases e.g. steel containing 0.4% carbon may be twice the strength of pure iron and with 1% carbon nearly three times as strong.

However as carbon content increases ductility reduces.

From 1 to 1.5% carbon, hardness increases but strength begins to decrease. When it contains more than 2´% carbon, the metal is classed as cast iron - having good castability, moderate strength and hardness but usually low ductility.

Steel Type	Approximate % Carbon
Mild Steel	Up to 0.25
Medium Carbon Steel	0.25-0.45
High Carbon Steel	0.45-1.5
Cast Iron	2.5-4.5

Mild steel and medium carbon steel can be used in closed, oil lubricated systems i.e. where corrosion is unlikely.

For water lubricated systems corrosion resistant steels should be used.

In very abrasive operating conditions hard, corrosion resistant steel sleeves should be used.

Hard sleeves generally use a carbide coating (e.g. tungsten or boron carbide) and exhibit a hardness around 50-60 Rockwell C.

Stainless steels whilst offering corrosion resistance are not highly wear resistant. Like aluminium, stainless steels containing chromium achieve their corrosion resistance by the formation of a protective oxide film. It is this oxide film that primarily results in lower wear resistance, particularly in abrasive conditions. General commercial grades offer hardnesses of around 10-15 Rockwell C (180-200 Brinell) which are acceptable.

Stainless steels are however available with relatively high hardness and are preferred if conditions are at all abrasive. Hardness should be greater than 30 Rockwell C.

The 18/8 stainless steels (austenitic) contain approximately 18% chromium and 8% nickel. They cannot be hardened by heat treatment but harden rapidly when cold worked. Molybdenum is often added to further increase corrosion resistance.

Another very good resistant alloy for sleeves is Inconel 625. This high nickel alloy (60%) work hardens, thus it is relatively easy to machine but hardens during operation.

SURFACE FINISH AND TOLERANCE

For Shafts

Experience has shown that a fine machine finish is an acceptable surface for FEROFORM bearings to operate against.

It is not necessary to polish the shaft liner or sleeve since this naturally occurs during the early operational period. A surface finish of 0.8 micro metre (32 micro inch RMS) can be specified.

Machining tolerances for shafts should be ISO tolerance h7(or h8).

For Housings

Out of round housings should be avoided. Again a H7 (or H8) ISO tolerance is preferred.

DIMENSIONING

LENGTH TO DIAMETER RATIO (L:D)

For industrial uses L:D ratios vary typically from 1:1 to 1.5:1.

An L:D of 1:1 can be considered optimum since it permits:

-adequate cross sectional area to provide acceptable bearing pressure.
-ease of alignment (alignment becomes progressively more difficult the longer the bearing).
-adequate outside surface area to permit retention by an interference fit.
-good pressure distribution throughout bearing length.
-allows a hydrodynamic film of lubrication to be readily established and retained.

Historically however for marine applications larger L:D ratios are used:

In oil lubricated propeller shaft systems typical permitted ratios are from 1.5:1 to 2:1.
In water lubricated propeller shaft systems typical permitted ratios are from 2:1 to 4:1.
For rudder bearings typical permitted ratios are from 1.8:1 to 2:1.

The historical reason for this is to keep the bearing pressure low.

Our experience indicates that the shortest possible L:D ratio should be used however Rules and Regulations of the Classification Societies must be adhered to.

Since TENMAT FEROFORM T grades are capable of operating at very high pressures (more than 60 MPa) we are currently evaluating in conjunction with leading Classification Societies use of reduced L:D ratios - particularly in propeller shaft applications.

WALL THICKNESS (W/T)

With a material such as FEROFORM exhibiting fairly high stiffness values wall thickness is not normally a critical design criterion.

Therefore FEROFORM bearings can be used to replace bearings of virtually any design/size envelope.

Nonetheless given freedom of design the optimum wall thickness recommended is 0.0625 d +2.5mm (where d is shaft diameter in mm).

This gives :
-sufficient thickness for incorporation of grooves if required.
-adequate wall thickness to permit interference fits to be used for retention.
-cost effective use of material volume (i.e. optimum costs).
-optimum stiffness (for ease of machine and fitting).

Should a thinner wall be required, the minimum recommended wall thickness is 0.05 d but TENMAT should be consulted if grooves are necessary in such a bearing.

GROOVE CONFIGURATION AND DIMENSIONS

A) Water Lubrication

Longitudinal lubrication grooves are recommended in accordance with Table 2

TABLE 2

Shaft Diameter (mm)	Number of Grooves	Approx Angle Between Grooves*	Grooves Width (mm)	Grooves Depth (mm)
20-79	4	72	6	0.33 W/T
80-159	5	60	10	
160-239	6	51	15	
240-319	7	45	15	
320-399	8	40	20	
400-479	9	36	20	
480-559	10	33	25	
560-639	11	30	25	
640-719	12	27	25	
720-799	13	25	25	
800-879	14	24	25	
880-959	15	22	25	
960-1000	16	21	25	

They are primarily important to permit abrasive particles to pass easily and quickly through the bearing. They do not assist in the promotion and retention of a hydrodynamic film of lubrication and therefore to enhance this aspect it is recommended that the bottom (6 o'clock) groove (in the loaded area) is omitted viz:

[* For propeller shaft bearings only]

T14 ID Groove Design for Water Lubricated Propeller Shaft Bearing

Optimum Wall thickness W/T = 0.0625 d + 2.5mm

Maximum groove depth g = 0.33 W/T. w = 2.5 g*. r = 0.33 g. N = number of grooves

NB. *No groove at 6 o'clock position for propeller shaft bearings.*

* Groove width is nominally 2.5 g, however to minimise the number of grooving tools required, use the averaged groove widths specified in Table 2 for each particular shaft diameter.

B) Oil Lubrication

Since closed (sealed) oil lubricated systems offer a clean operating environment longitudinal grooves are not necessary and therefore it is recommended that “lead-in” (washway) grooves only are used, positioned at 9 o’clock and 3 o’clock, (or 10 o’clock and 2 o’clock possibly in the case of twin screw vessels)

C) Grease Lubrication

Grease lubricated systems are generally used in very slow moving or oscillatory motion applications such as rudders.

Here grooves are not necessary, although in some installations -dependent on the method of supplying grease to the bearing - annular or closed end grooving may be used.

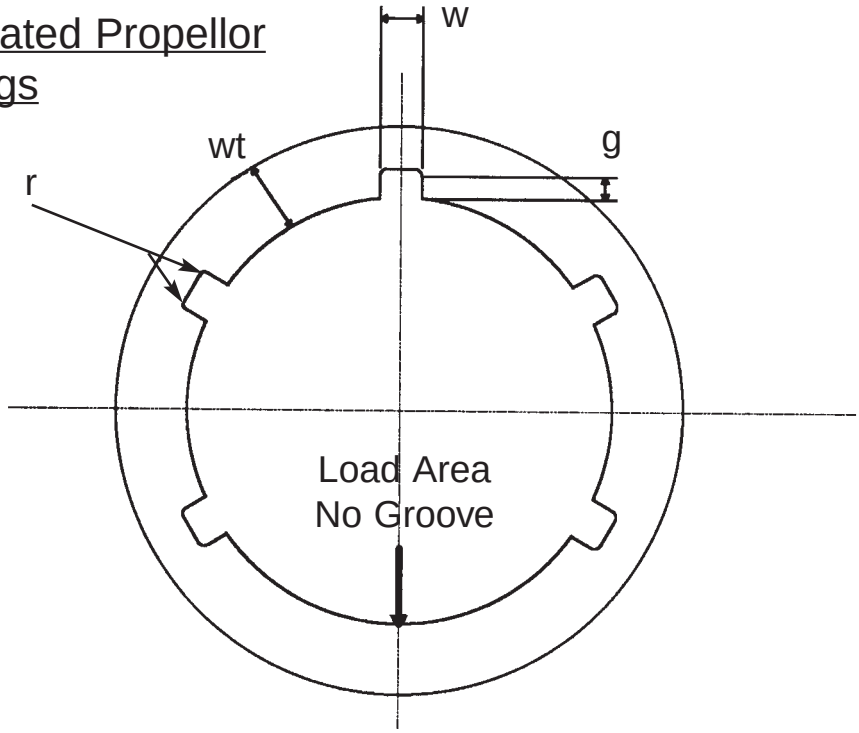
For grease lubricated propeller shafts, grooves should always be used as indicated in “water lubrication” section.

FEROFORM T Grade ID Groove Design for **WATER** Lubricated Propeller Shaft Bearing

Optimum Wall thickness W/T = 0.625 d + 2.5mm

Maximum groove depth g = 0.33 W/T. w = 2.5 *. r = 0.33g. N = number of grooves

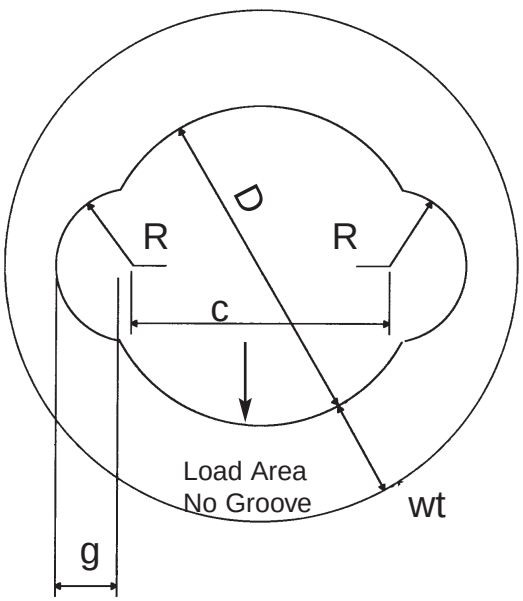
Water Lubricated Propellor Shaft Bearings

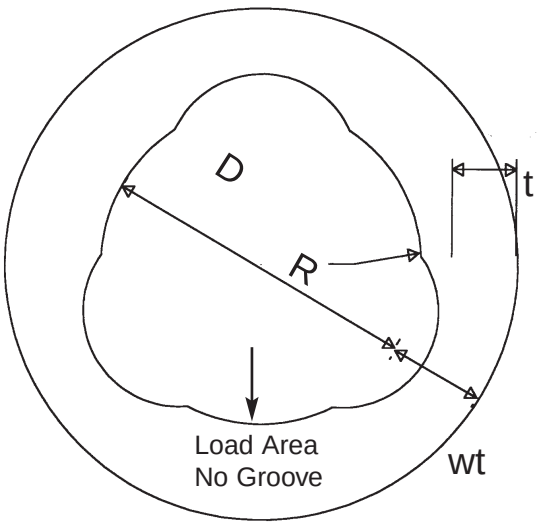


FEROFORM T Grade ID Groove Design for **OIL** Lubricated Stern Tube

Optimum Wall Thickness W/T = .0625 d + 2.5mm
R = 0.4 d. g = 0.025 d

Wash Ways for Oil Lubricated Stern Tube Bearings





OD - ID CALCULATIONS

The following pages detail the method of designing FEROFORM Bearings.

Two methods are described:

A) Graphical format where machining sizes can be taken directly from the graphs for finished or semi-finished bearings but in ONLY for bearings with optimum wall thickness.

See graphs 1-7

B) Calculations from first principles.

See pages 18-20

C) Computer Programme.

See page 21

(A) GRAPHICAL FORMAT FOR FEROFORM T GRADE BUSH OD AND ID DIMENSIONING FOR MARINE STERN TUBE AND RUDDER BEARINGS

Only with Optimal Wall Thickness

For fully machined water lubricated Stern Tube and Bracket Bearings which are pressed into the housing (without further machining), use Graphs 1 and 2.

For fully machined oil lubricated Stern Tube Bearings which are pressed into the housing (without further machining), use Graphs 1 and 3.

For fully machined water and grease lubricated Rudder Bearings which are pressed into the housing (without further machining), use Graphs 1 and 4.

For semi-finished lubricated Stern Tube and Bracket Bearings where the bore is finish machined after the bearing is pressed into the housing, use Graphs 1 and 5.

For semi-finished lubricated Stern Tube Bearings where the bore is finish machined after the bearing is pressed into the housing use Graphs 1 and 6.

For semi-finished and grease lubricated Rudder Bearings where the bore is finish machined after the bearing is pressed into the housing, use Graphs 1 and 7.

(B) DIMENSIONING FROM FIRST PRINCIPLES

1) Interference Fit

FEROFORM bearings are usually retained in their housings by using an interference fit.

Minimum recommended values are given on Graph 8 as are suggested achievable manufacturing tolerances.

For oil lubricated and sometimes water lubricated propeller shaft bearings some form of additional mechanical fixing such as keys or locking strips is recommended.

2) Running Clearance

Recommendations of bearing running clearance for a given shaft diameter are indicated on Graph 9. The amount of running clearance is critical to the performance of a bearing.

Where applicable, such as rudder bearings, society regulations should be consulted with respect to minimum running clearances.

3) Swell

Is a linear surface effect and not volumetric. We calculate swell as 0.5% x (OD-ID).

FEROFORM grades are stable in oil and greases.

In water the longitudinal (axial) swell of `T' grades is 0.2%.

4) Bore Closure

Graph 10 indicates the optimum wall thickness and bore closure allowance to be made when the wall thickness is greater than the optimum size. The wall will compress by a certain percentage (shown on the graph) depending on how over thick it is.

Min wt = 0 05 d

5) **Thermal Expansion**

TABLE 3

Material Grade	Normal to Laminae x 10^6/C	Parallel to Laminae x 10^6/C
F21/24	60	20
F363	45	15
F36	41	13
F61	16	8
F21	100	100
T11/T12/T14	50	45

The above data is typical for the materials up to their normal maximum operating temperatures. T11/T12/T14 have a thermal contraction of 20 x 10-^{6}/°C on diameter (normal to laminae) from +20° to -70°C.

6) **Lubrication Grooves**

a) Water Lubrication

Multi-grooved configuration is generally adopted in plain bearings, or alternatively, stave construction for larger diameters.

See Groove Configuration on Page 14 for dimensions.

b) Oil Lubrication

Feed-in (washway) grooves are usually incorporated into oil lubricated propeller shaft bearing design to promote an hydro-dynamic fluid film.

See Groove Configuration on Page 16 for dimensions, note this is for the design of grooves only, suitable arrangements must be made for the free flow of heated oil out of the bearing area/system.

For those wishing to undertake `T' grade rudder or propeller shaft bearing calculations, a brief calculation procedure is shown below.

A more detailed method (for Industrial Bearings) is shown in TENMAT's Wearing and Bearing brochure. (Note dimensions are in millimetres).

Calculate Bearing Outside Diameter.

i. Add minimum interference fit from Graph 8 to maximum housing diameter = 0D min.

ii. Add machining tolerance to OD min = OD max

Calculate Bearing Inside Diameter.

i. Determine from Graph 9 the minimum Running Clearance for rudder or stern tube (or use Shipping Society recommendations) = RC min.

ii. Calculate swell allowance (in water) by:-

OD - ID x 0.005 = SA

50% swell allowance should be added to oil lubricated bearings in case of seal failure.

iii. Determine bore closure by calculating maximum interference.

I max = OD max - minimum housing

If wall is optimum or less than optimum thickness BCF = 1, but if wall is thicker than optimum determine Percentage Factor from Graph 11. That is if wall is twice optimum, then use 50% BCF.

Bore Closure = I max x BCF = BC

iv. Calculate Thermal Expansion for oil lubricated propeller shaft bearings (or if applicable for warm water applications) using Table 2.

Expansion = OD - ID x 50 x 10^{-6} x (65 - 20°C Temperature rise) = TE.

(NB 65 C is normal high temperature alarm setting).

v. Therefore ID machining size is given by - max shaft dia + RC min + SA + BC + TE = ID min.

ID max = ID min + Machining tolerance.

Calculate Bearing Length

Society rules generally state what length to shaft diameter may be used for particular vessel bearings, be they water or oil lubricated propeller shafts or rudder bearings. For non-society classed vessels, 2:1 L:D oil propeller shaft bearing ratios can be considered and typically 1 5 L:D oil propeller shaft bearings ratios can be considered and typically 1 25:1 L:D ratio for rudder bearings.

Calculate Grooving Configuration

Grooving configurations can be calculated using Table 2 and the Groove design drawings on Page 14.

BEARING CALCULATIONS - BY COMPUTER PROGRAMME

TENMAT offer the facility of `T' grade Marine Bearing calculations by Computer, written in MS DOS GWBASIC for IBM compatible PC's, for rudder bearings and oil, water or grease lubricated propeller shaft bearings.

Please consult TENMAT on [+44] (0)161 872 2181 or Approved Distributors throughout the world for details.

INFORMATION REQUIRED FROM THE USER

In order that we may offer advice on optimum FEROFORM grade, design configuration and dimensional fits etc, it would greatly assist us to have the following information:

Type of Equipment:
Specific Application:
Speed: rpm or surface velocity if fully rotating/ cyclic speed if oscillating.
Operational Temperature Range:
Lubrication: If not sealed, recirculating system - condition of lubricant e.g. abrasive content, temperature.
Operational Pressure (or load):
Housing Diameter (min/max):
Shaft Diameter (min/max):
Length of Bearing:
Preferred method of retention (if any): Interference, Mechanical, Adhesive Bonding.
Preferred Method of fitting (if any) e.g.: Hydraulic Press, Freeze Fitting.
Any additional related information or comment:

If replacing another material, details of any problems associated with that material or details of required improvements in performance etc would be useful. For quotation purposes we would additionally need to know the quantity and whether the material is to be supplied fully finished (ready-to-fit) or semi-finished with allowances for on site finish machining (e.g. by shipyard).

RETENTION METHODS

Any conventional method of retention can be adopted with FEROFORM bearings such as:

Interference Fit

The level of interference required is given in Graph 8. This is the preferred method of retention of a full configuration bearing since not only is installation quick and easy but additional benefits are gained:

1. The recommended amount of interference fit should prevent either bearing rotation or axial movement. It is normal practice to additionally use an end keeper ring/shoulder as an additional safety precaution.
2. An interference fit provides intimate contact between the housing and bearing OD alleviating the possibilities of water ingress and thus preventing corrosion of the housing bore. Also bearing ovality that can occur in machined bushes is removed following
3. Experience has shown that a light film of 'flushing' oil is condusive on the OD for ease of fitting.
4. When a bearing is fitted with an interference there will be an associated amount of bore closure.

In the event of temperature decrease the resultant contraction will mean a loss of some of the interference (accounted for in the dimensioning calculation) which also means a reduction of bore closure amount. This reduction of bore closure would normally increase the ID but is approximately balanced by the thermal contraction effect. Thus the running clearance remains roughly constant i.e. it will not significantly change with temperature decrease.

Mechanical

Traditionally used mechanical methods of retention can be used.

The methods should ensure that no rotational or axial movement is possible.

For example: To prevent rotation:-
Anti-rotation key (for full bearings)
Longitudinal keeper strip (for stave bearings)
To prevent axial movement:-
End keeper ring and forward stop
Flange - locked by screws
Stepped housing and end keeper ring

Bonding

1. **Adhesive Bonding**

FEROFORM bearings may alternatively be bonded into a housing. Bonding is not the preferred method of retention since removal is made more difficult but may be necessary if:

i) The wall thickness is insufficient to allow retention by interference fit.

ii) To compensate for a corroded or out of round housing.

Our Technical Department can offer advice on adhesive selection. A two part, cold cure epoxy adhesive is normally acceptable. (see also no 3 & 4 below)

2. **Using Chocking Compound**

Epoxy chocking compounds (such as Chockfast Orange, Epocast or Belzona) can fill large gaps and can be readily poured between housing and bearing; hence alignment can be easily achieved by positioning the bearing and then pouring chocking compound to fill the gap between bearing and housing.

Alternatively a dummy bearing the OD of which has been coated with mould release agent can be used during the pouring and curing operation.

When the chocking compound has fully cured, the dummy bearing can be removed and a finished FEROFORM bearing fitted by interference via freeze shrinking.

3. FEROFORM materials can be bonded together. For example, where two (or more) bearing sections need to be joined then the ends of each section can be machined with spigot/recess to a transition fit condition and a cold cure two part epoxy adhesive used. For additional security, radial holes can be drilled through the spigot join overlap and FEROFORM dowels be bonded and knocked into position.

4. Typical adhesives which can be employed are BOSTIK M890 and ARALDITE 2004. NOTE. Tenmat are **NOT** manufacturers of any adhesives. Therefore, users are recommended to follow the manufacturers recommendations.

MACHINING

1) Bearings

a) TURNING OD AND ID

RPM's

Finished Diameter mm inches	Up to 50 2	Up to 100 4	Up to 150 6	Up to 200 8	Up to 250 10	Up to 300 12	Up to 350 14	Up to 400 16	Up to 450 18
RPM	1400	1000	500	400	340	300	220	180	160

NB If turning ring diameters from sheet use RPM x 2 with the same feed rates.

FEED RATES

	SURFACE FINISH		
Operation	Rough	Standard	Fine
OD + ID	0.4 mm/rev	0.2 mm/rev	0.1 mm/rev
Facing	0.25 mm/rev	0.1 mm/rev	0.08 mm/rev
Partinf off	0.1 mm/rev	0.08 mm/rev	0.05 mm/rev

NB For machining of washways use OD + ID operation.

Stock Removal Rate

10mm on diameter (roughing)
3mm on diameter (finishing)

TOOLING

Tungsten carbide is most often utilised with polycrystalline diamond tipped tooling used for large batch orders. For small quantities and one-off's, High Speed Steel tooling is perfectly adequate. In all machining applications a sharp cutting edge is of paramount importance and the grade of carbide recommended is K10/K68 (ISO designation).

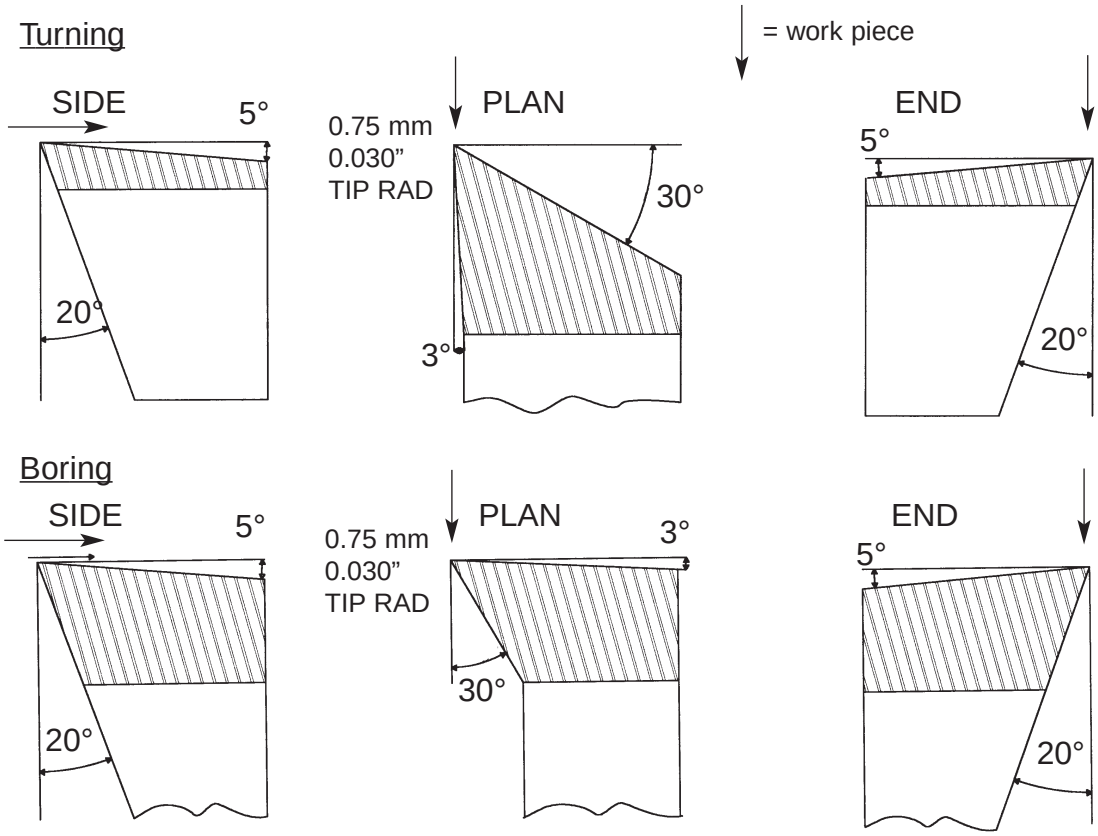
When turning large diameter or thin wall tubes a dummy centre should be used in the bore at the chuck jaw end to prevent the tube distorting, a tight fit 'bung' or revolving centre is to be used at the tailstock end of the tube. Large diameter tubes can be supported with a suitable steady, however as steadies

may leave marks it may be desirable to have an allowance on OD to clean up afterwards.

Before finish cuts are applied the material should be left to cool to ambient temperatures to allow for frictional heat generated in roughing out to be dissipated. Note the finish cut should be a minimum of 1mm to ensure that cutting, rather than rubbing takes place.

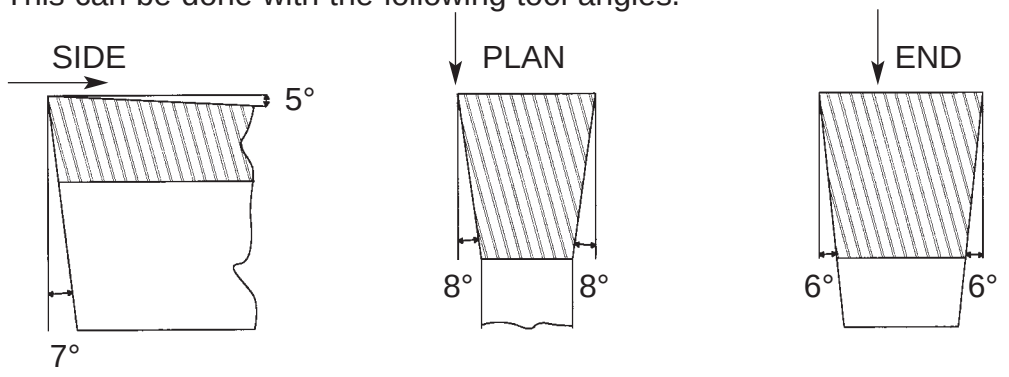
Turning operations can be speeded up by approximately 50% if a coolant is used (i.e. water), but little improvement to the surface finish will result, only extended tool life.

Tooling Geometry for Turning and Boring



b) PART OFF

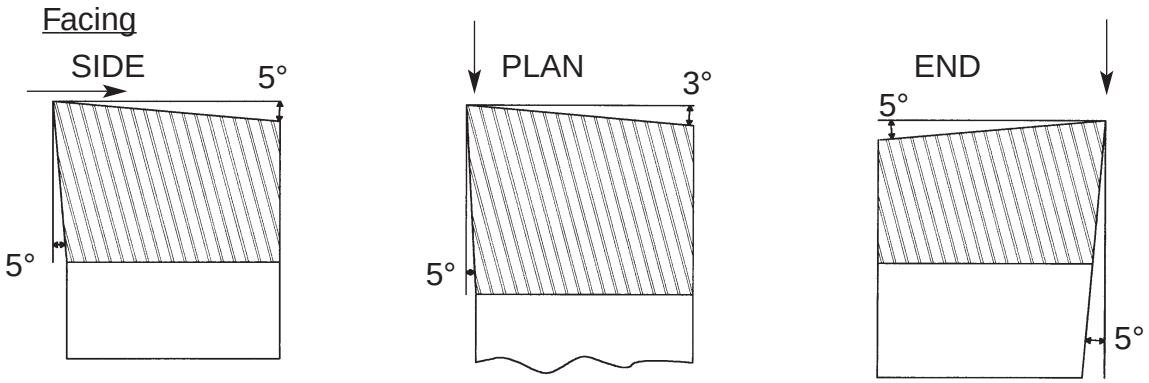
This can be done with the following tool angles.



c) FACING

This can be done with the following tool angles.

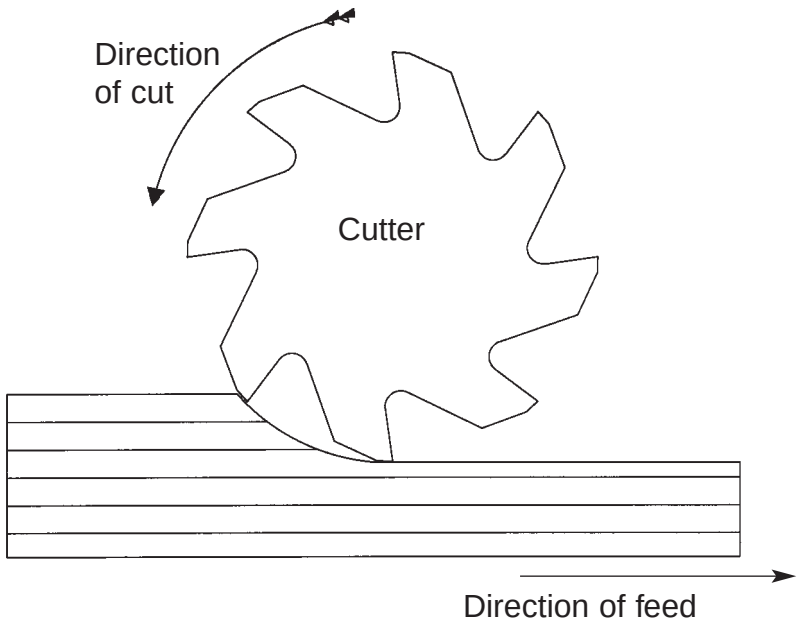
Facing



d) MILLING

Again carbon tipped tooling should be used. When using side and face cutters the climb milling method should be employed, see below.

Side and Face Cutter



Typical Data using 200mm Diameter Cutters with 12 Tips

Width of Cut	Max Depth of Cut	Speed (RPM)	Feed
0 - 12 mm	25 mm	600	0.6 mm/rev
12 - 25 mm	20 mm	450	0.5 mm/rev
25 - 40 mm	12 mm	350	0.25 mm/rev
40 - 50 mm	6 mm	300	0.15 mm/rev

Slab Milling

For machining slots, rebates or shapes on FEROFORM T14 a spiral teeth design is recommended.

OD of Cutter	Width of Cut	Speed (RPM)	Feed
75 mm	75 mm	300	0.4 mm/rev
100 mm	75 mm	250	0.25 mm/rev

End Milling/Slot Drilling

Either solid carbide or tipped cutters are recommended with a straight or spiral design. The climb milling method should again be employed.

Typical Data

OD of Cutter	Max Depth of Cut	Speed (RPM)	Feed
6 mm	10 mm	600	0.4 mm/rev
12 mm	20 mm	500	0.25 mm/rev
20 mm	40 mm	400	0.25 mm/rev
25 mm	60 mm	300	0.25 mm/rev

e) BAND SAWING

Rough cutting may be done with a Band Saw carbide steel blade 25mm wide with 7 teeth/25mm. For improved results a diamond electroplated blade can be used, free hand feed rate but again not forced as excessive heat will be quickly generated.

f) CIRCULAR SAW

Due to large heat generation the best results are obtained by cutting wet with diamond blades (metal bonded type), but can be cut dry at 2000 RPM x 3m/min feed rate using a 300mm diameter carbide tipped saw blade with 3.2mm cut (tooth width) and 50 teeth.

When cutting through material in excess of 40mm thick it is recommended that 2 or more depth cuts are taken.

For example 50 mm thick in 2 cuts
90 mm thick in 2/3 cuts

This is in order to prevent excessive heat generation leading to loss of tension in the saw blade. If cut wet the size of the blade used determines the maximum depth/thickness.

g) DRILLING

Carbide tipped or masonry drills are recommended but high speed steel drills can also be used for small batch work.

Typical Data

Drill Size	Speed (RPM)	Feed
3 mm	800	1 mm/sec
6 mm	700	1.25 mm/sec
12 mm	600	1 mm/sec
19 mm	400	0.75 mm/sec
25 mm	250	0.6 mm/sec
38 mm	200	0.4 mm/sec

NB Drills with a standard helix spirl are to be used and these must be continually cleared/pecked.

h) GROOVING

For example Bush size: 500mm OD x 450mm ID x 600mm long with 25mm slots through bore 12mm deep.

Machining of Longitudinal Grooves in Feroform

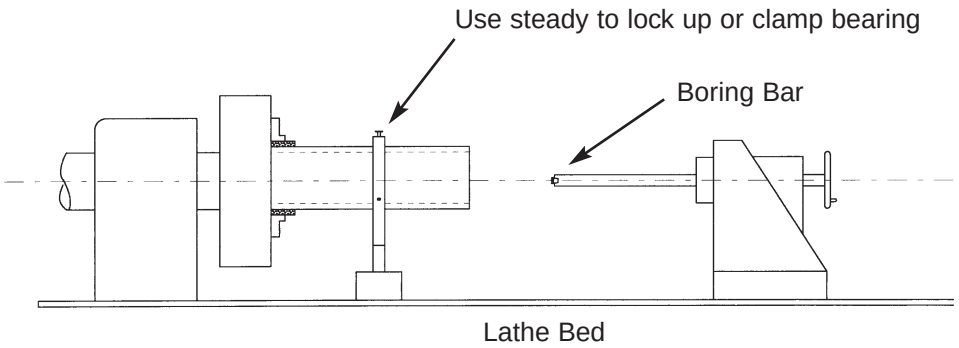
Recommended	Alt 1	Alt 2
MACHINE - Vertical bored right angle head	Shaper	Lathe
TOOLING - Spiral flute drill (carbide tipped)	Specially extended tool bar at 660 mm long with carbide tip welded to 90°. Tip to have maximum 5° clearance on all sides. Improvised workholding required.	As for shaping
DEPTH OF CUT - Up to 6.4 mm (½") deep per pass	0.5 mm - 1 mm (0.02" to 0.04") per stroke	As for shaping
SPINDLE SPEED - 500 rpm	Stroke rate 9.5 m/min	As for 1
FEED RATE - 0.25 mm/rev		

IMPORTANT: Wherever possible, final bore **after** grooving to improve results (stock removal of 0.5mm total).

If cannot disengage spindle drive from feed

Lathe

Using steel “running” bearing as steady gripped in chuck with its’ bore machined to suit OD of bearing being grooved.



Graduations on chuck to equispace grooves if can disengage spindle, if not mark each bearing.

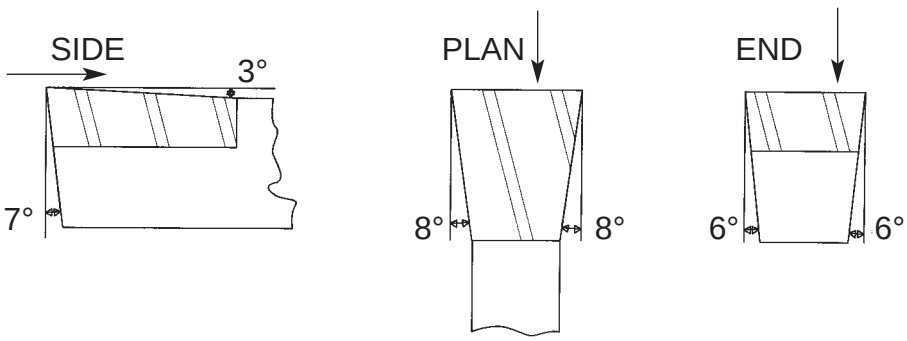
Grease must be applied to the OD of the bearing running in the steel check ring to prevent over heating.

Engage feed traverse, forward then reverse, taking depth cuts as per shaping detail until desired depth is achieved. Obviously if it is possible to disengage the spindle rev’s still use feed and the need for a `running’ bearing disappears.

Axial Grooves

For tooling angles see below and for typical speeds and feeds see shaping information.

Sketch B



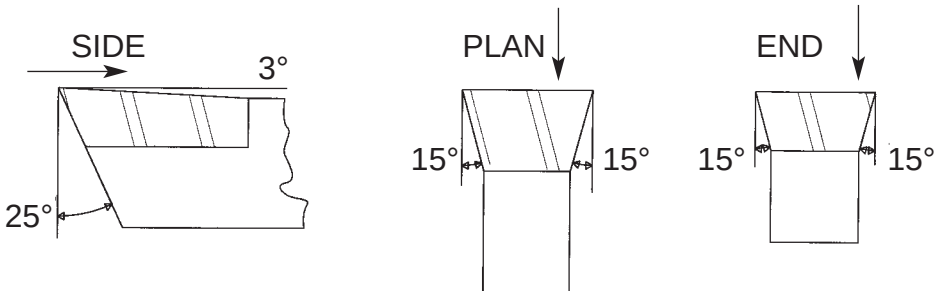
Right-angle Head

Minimum ID approximately 250mm.

Supplier: Centreline Machine Tool Company, Leicestershire. Kennametal Bristol Erikson), Bristol.

Spiral Grooving

This should be done with the following tool angle.



It is recommended that internal spiral grooving be done using a right angle head attachment to a vertical borer machine with a spiral/straight slot drill.

See end milling/slot drilling for speed/feed/depth of cut data.

Spiral grooving with a single point tool can be carried out on a lathe but great care must be taken to ensure a keen, sharp cutting edge is used along with small depth cuts.

For example - 12mm wide groove on a lathe in a 150mm ID.

Cutter Details - See sketch above.
Spindle Speed - 50 rpm.
Depth of Cut per pass - 0.25mm.
Pitch - 100mm.

Spiral grooving using Power Driven `live tooling' on a lathe results in a good quality groove achieved in half the time. An adapted thread grinding lathe attachment is suitable.

i) HACK SAWING

The FEROFORM `T' grades can be easily cut using a hacksaw with a preferred blade range of 10 to 18 teeth per 25mm.

j) TAPPING

This can be carried out using a normal tap wrench or a radial arm drill with `HAND TAP' selected.

For example: 80 rpm for 10mm Whitworth.

Please note with drilled or tapped holes clearance should be allowed for at the bottom of the hole or thread to prevent excessive delaminating forces caused by inserts, bolts etc.

k) PLANING

FEROFORM `T' grades can be hand or power planed with results dependent upon operator skill. Surform type hand planes may give better results. When manually planing a standard wood plane with a very sharp edge should be used. For power planing spindle speeds should be 20,000 rpm, stock removal no more than 0.8mm per pass and solid carbide blades used. Power planing is obviously the recommended method.

l) SHAPING

Shaping operations can be carried out on FEROFORM grades but wherever possible an `intermittent' cutting alternative is recommended.

Tooling clearances should be as for turning of axial grooves on Page 29.

Typical Data

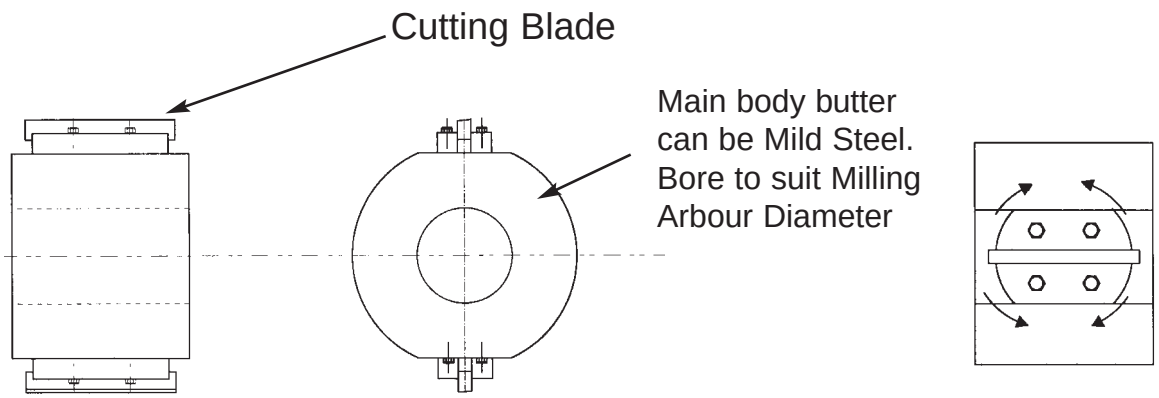
Width of Tool	Depth of Cut (per stroke)	Stroke Rate	Length
3 mm	1 mm	96 st/min	130 mm
10 mm	0.5 mm	46 st/min	380 mm
16 mm	0.25 mm	33 st/min	600 mm
25 mm	0.25 mm	17 st/min	600 mm

Conversion Table

Metric (mm)	Imperial (inches)
0.05	0.002
0.10	0.004
0.15	0.006
0.20	0.008
0.25	0.010
0.40	0.015
0.50	0.020
0.60	0.025
0.75	0.030
1.00	0.040

2) STAVES

Cutter Design for Concave Profile



When opposing flat blades are placed at diametrically opposite angles from 180 , they result in a machined radius.

Typical speeds and feeds are 400 rpm @ 500mm per min with 1.5mm stock removal. Cutting blades are high speed steel (for small batches) or solid carbide/carbide tipped (for larger batches). Clearance from cutting edge is 15-20°.

Convex Profiles

Same cutter body to be used but all blades must be ground to the correct radius.

3) SHEETS

Sanding

`T' grades can be sanded or wet ground to thickness (wet grinding results in improved finish).

Typical Data

Sanding*

Belt Grit Size	Stock Removal	Feed Rate	Approx Surface Finish
P36	0 25mm per pass	3 metre/min	12 µm
P80	0 12mm per pass	5 metre/min	6 µm

Wet Grinding*

Stone Grit Size	Stock Removal	Feed Rate	Approx Surface Finish
36	0.25mm per pass	3 metre/min	1 µm

* Machines used were "Grindmaster" sander with 900mm wide belt (Machine built by Ellesco's) and "Rowlands" wet "duplex" grinder.

4) HAND FINISHING

Filing

FEROFORM `T' grades can easily be filed using a medium grade file which is in good condition.

Emery Cloth

The use of emery paper can improve the surface finish particularly if `wet and dry' up to 400 grit is used.

Surforming

This has been shown to be an extremely good method of bulk material removal for roughing of FEROFORM.

5) REMOVAL OF DUST AND SWARF

It is essential that good housekeeping is maintained on all machines and local legislation is adhered to.

Swarf generated from cutting of staves is much finer (chip broken) and therefore easier to extract as it is being generated. Swarf from continuous contact cutting operations, i.e. shaping and turning needs to be bagged off at the machine with care taken not to allow the turnings to clog up any extraction equipment used.

Safety, Handling and Storage

See FEROFORM Product Data Sheet.

FITTING METHODS

Press Fitting

It is recommended that bearings to be fitted by pressing have an entry chamfer to facilitate starting.

Once started, pressing should be a continuous operation until fully installed since, if stopped, re-starting may require extra pressing force.

The housing should be round, with a truly parallel bore, clean and grease free.

The graph indicates the nominal fitting force for T14. It is based on optimum wall thickness and 2:1 R:d ratio. For L:d ratios over 2:1, higher forces than those indicated can be expected.

NOTE Bearings may be supplied in more than one piece. Since water lubricated bearings have longitudinal grooves in the base it is important to ensure that grooves line up. To assist, a keeper bar placed in a groove will help.

It is suggested that an annular groove is machined into one end of each length of a multi-piece bearing to facilitate flow of water through the bearing even if the grooves are not fully aligned.

The annular groove should be to the same depth as the longitudinal grooves.

Freeze Fitting

FEROFORM bearings can be shrink fitted by freezing in either dry ice (solid CO2) or liquid nitrogen.

In both cases extreme care should be taken since:-

1.The extremely low temperature of these products can cause severe burns or frostbite.

2.Gassing off of these products displaces air leading to possible asphyxiation unless adequate ventilation is supplied.

If this method of freeze fitting is used manufacturer’s guidance notes must be followed.

The temperature of dry ice is -79°C and liquid nitrogen is -196°C.

The freeze down time for FEROFORM bearings is shown in Table on page 36.

Once frozen they can be slid into the housing without any difficulty i.e. the amount of shrinkage will be greater than the amount of interference.

	Liquid Nitrogen	Dry Ice
Freezing Down Time	½ hour	1½ hour
Warming Up Time	2½ hour	1½ hour

These are **typical times** for guidance only, and will vary due to ambient conditions, wall thickness, bearing diameter etc.

On warming back to room temperature the interference fit will be sufficient to hold the bearing in place but normally, for added safety, a forward stop and an end keeper ring is suggested.

For large bearings supplied in more than one piece care should be taken to align the grooves.

This is quite easy when freeze fitting but it is recommended that each piece be allowed to warm and secure before installing subsequent pieces.

When freeze fitting staves it is important to ensure that each stave is covered with the cooling medium otherwise some may not fully shrink.

Freeze fitting can be used with all stave constructed bearings whether secured by interference fit utilising a longitudinal keeper strip or when fitting dovetailed staves into a dovetailed housing.

Adhesive Bonding

The adhesive manufacturers instructions must be followed. In general terms both housing bore and bearing OD should be clean and grease free.

The machined finish of the housing and bearing will provide adequate mechanical keying which further improves the adhesive bond.

Since no interference is involved there should be a clearance between the OD of the bearing and the housing bore.

The required clearance varies according to the adhesive used and therefore the adhesive suppliers recommendations should be sought.

Similarly cure times vary; for example a cold cure, two part epoxy may take 6-8 hours to harden and up to 48 hours to achieve full strength at normal ambient temperatures.

APPROVALS

Classification Societies approve FEROFORM T grades for the following:

- Oil lubricated (sealed system) stern tube/propeller shaft bearing.
- Water lubricated (open system) stern tube/propeller shaft bearings.
- Grease lubricated propeller shaft bearings.
- Grease, water or oil lubricated rudder bearings.

Notes

Allowable pressures and L:D ratios vary slightly between Societies. Permitted running clearances also vary slightly and for this reason the TENMAT recommendations quoted are minimum allowable values.

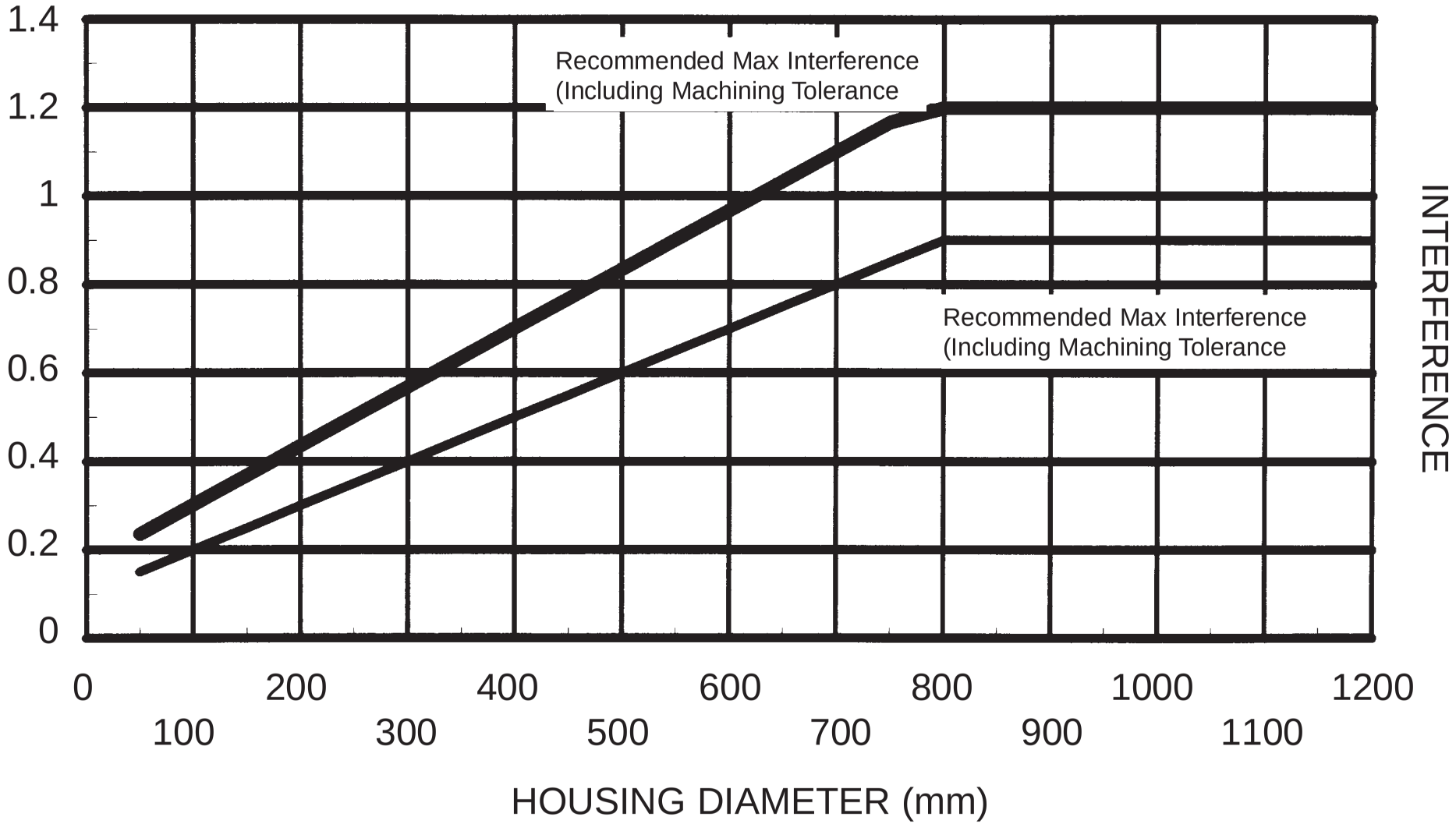
Societies Having Approved FEROFORM include:

- Lloyds Register of Shipping
- American Bureau of Shipping
- Det Norske Veritas
- Bureau Veritas
- Germanischer Lloyd
- Nippon Kaiji Kyokai
- Korean Register of Shipping
- Biro Klasifikasi Indonesia
- China Classification Society
- China Corporation Register of Shipping
- Registro Italiano Navale

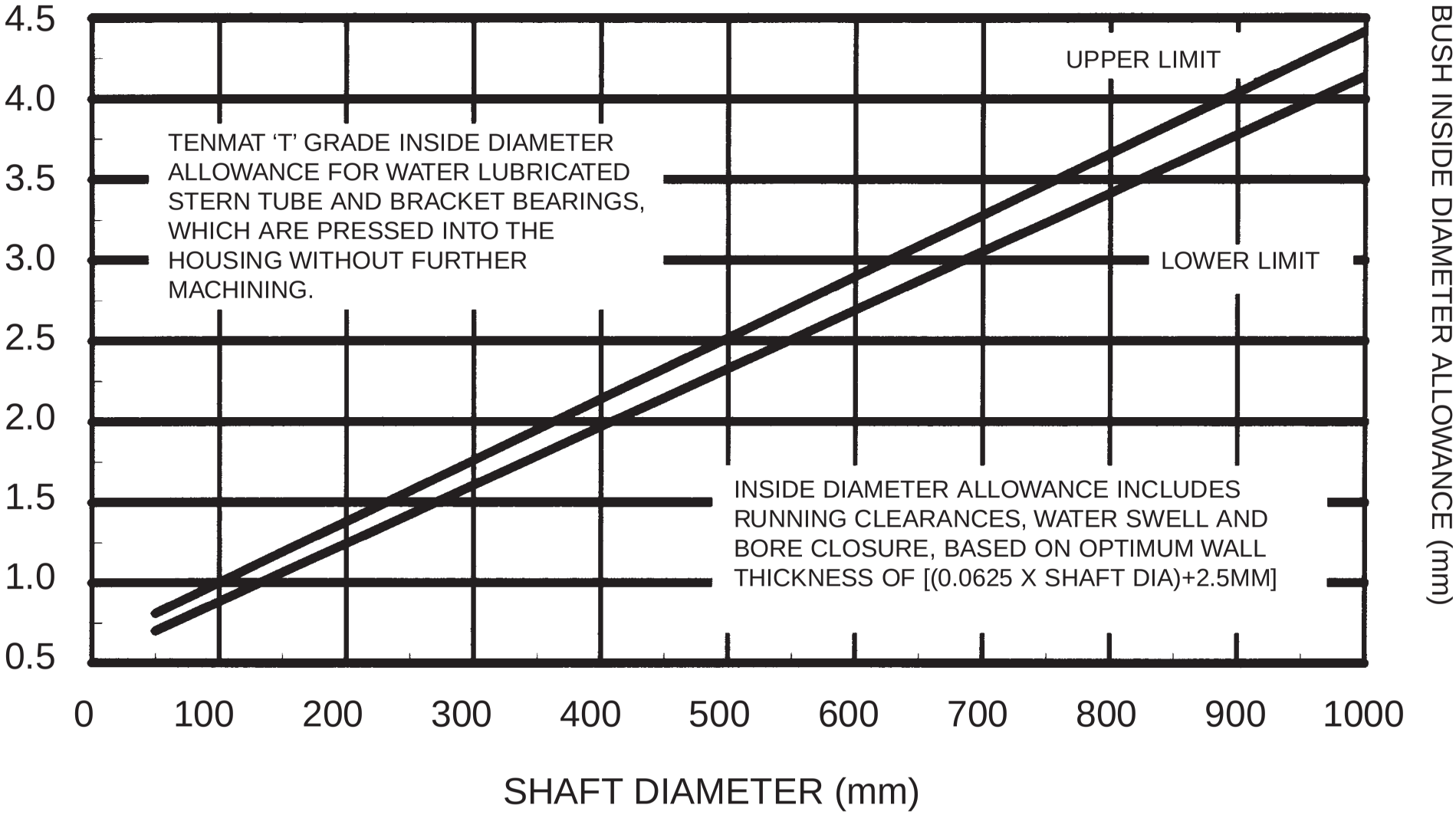
The information herein is presented in good faith, but TENMAT does not warrant the conformity of its materials to the listed properties or the suitability of its materials for any particular purpose. In the event of any uncertainty regarding suitability for any application, please contact Tenmat and ask for our Technical Services Department on [+44] (0)161 872 2181.

GRAPH 1

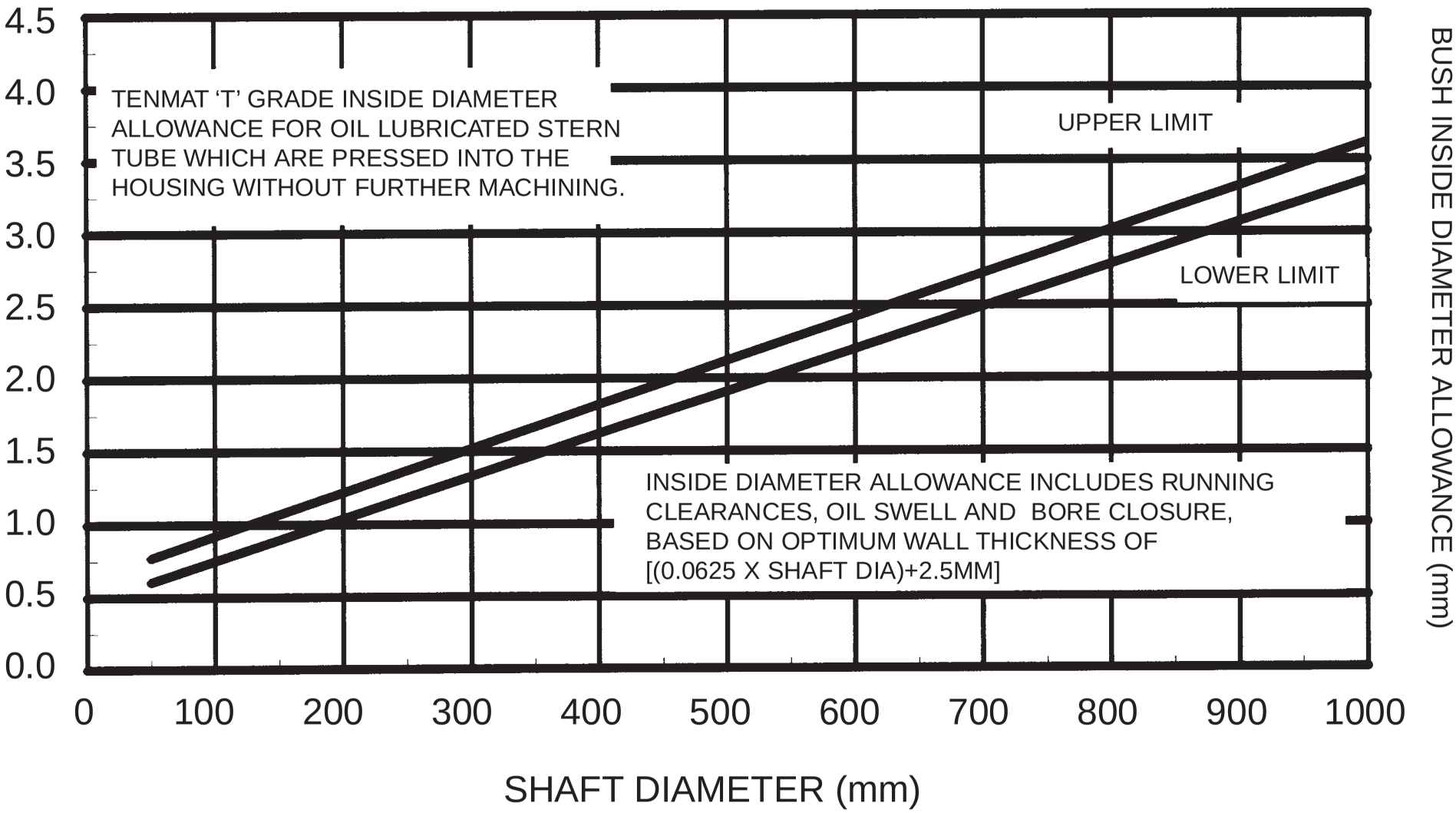
TENMAT “T” GRADE INTERFERENCE



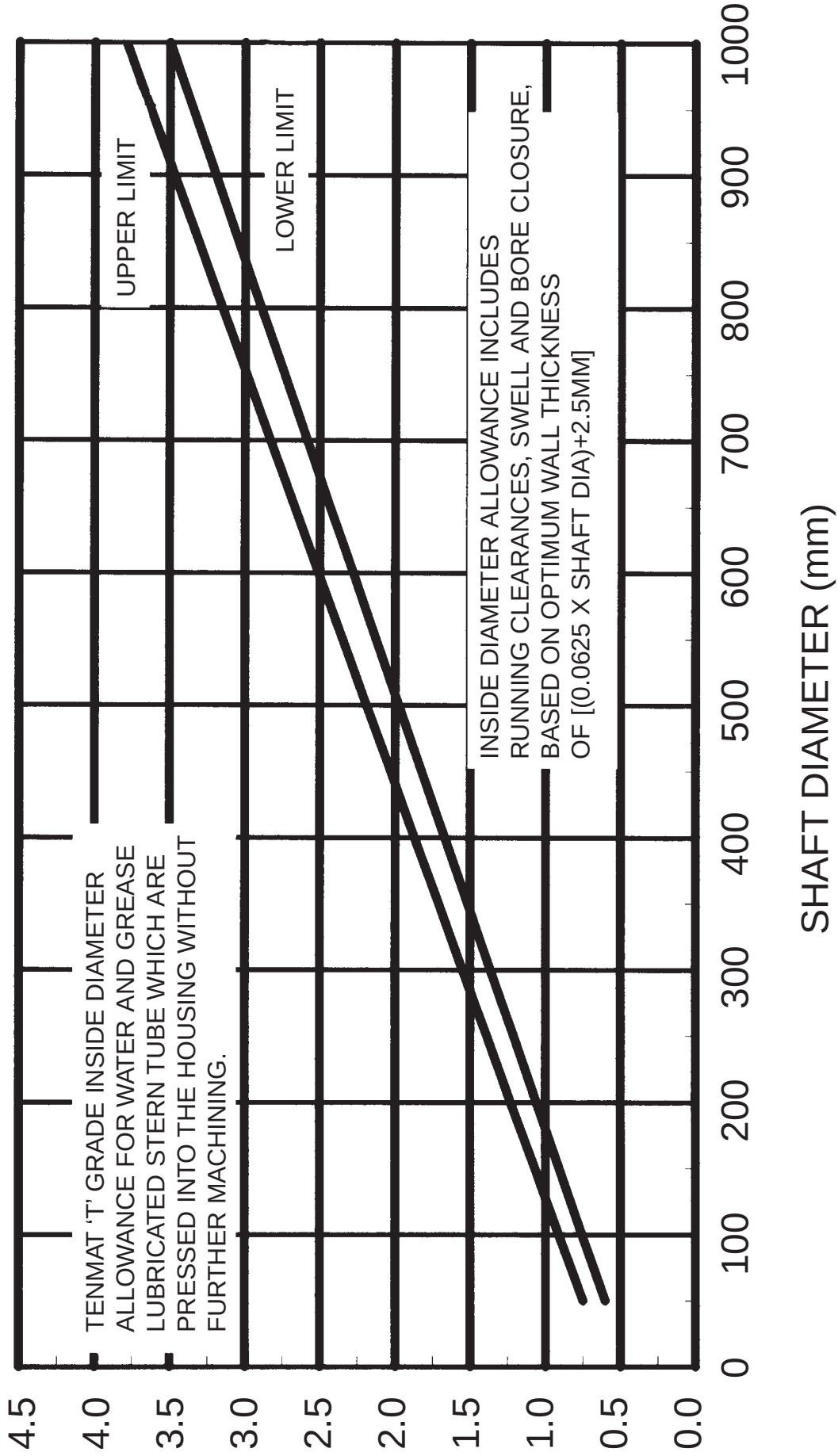
GRAPH 2


4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0
100
200
300
400
500
600
700
800
900
1000
UPPER LIMIT
LOWER LIMIT
TENMAT 'T' GRADE INSIDE DIAMETER ALLOWANCE FOR WATER LUBRICATED STERN TUBE AND BRACKET BEARINGS, WHICH ARE PRESSED INTO THE HOUSING WITHOUT FURTHER MACHINING.
INSIDE DIAMETER ALLOWANCE INCLUDES RUNNING CLEARANCES, WATER SWELL AND BORE CLOSURE, BASED ON OPTIMUM WALL THICKNESS OF [(0.0625 X SHAFT DIA)+2.5MM]
BUSH INSIDE DIAMETER ALLOWANCE (mm)
SHAFT DIAMETER (mm)

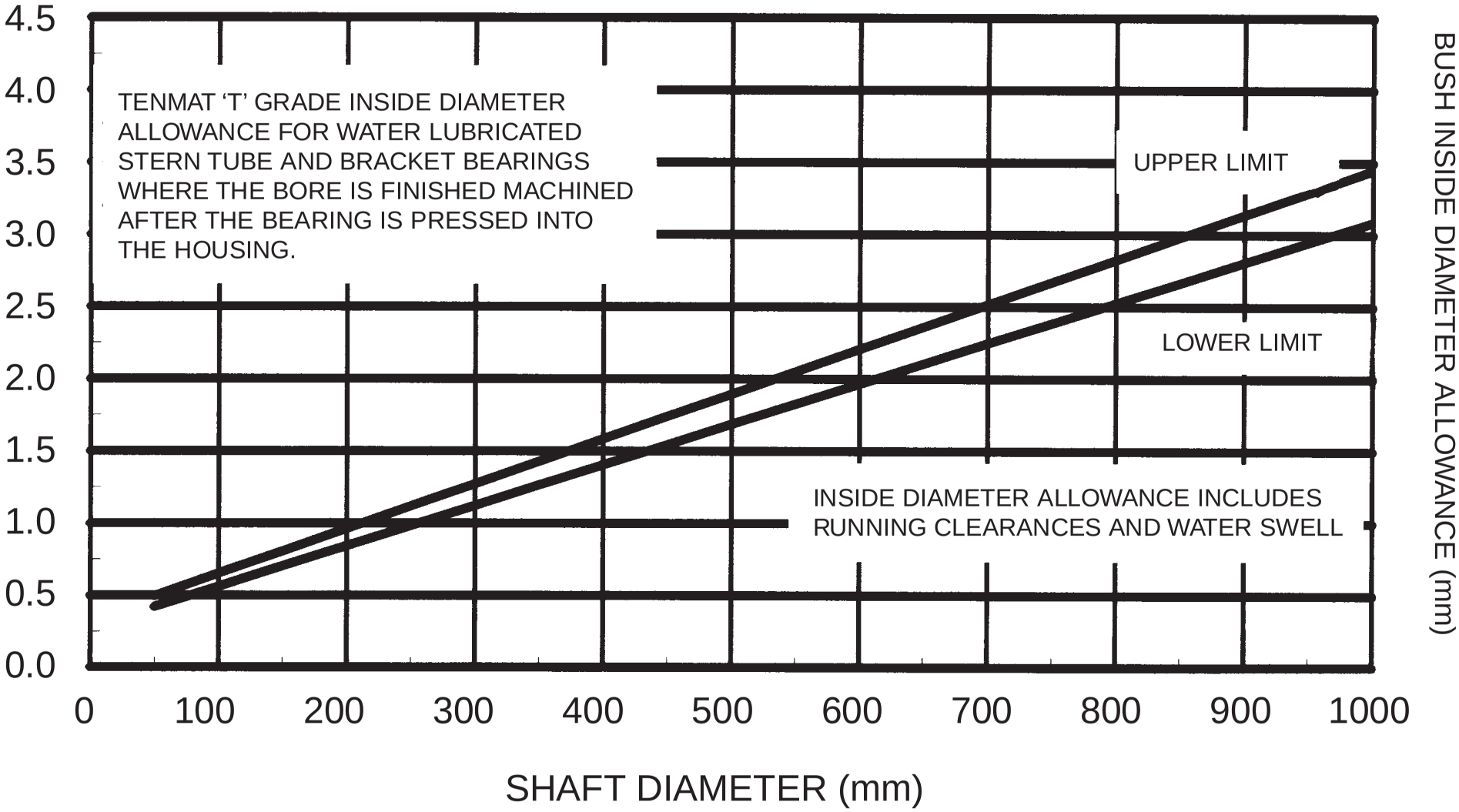
GRAPH 3


4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
TENMAT 'T' GRADE INSIDE DIAMETER ALLOWANCE FOR OIL LUBRICATED STERN TUBE WHICH ARE PRESSED INTO THE HOUSING WITHOUT FURTHER MACHINING.
UPPER LIMIT
LOWER LIMIT
INSIDE DIAMETER ALLOWANCE INCLUDES RUNNING CLEARANCES, OIL SWELL AND BORE CLOSURE, BASED ON OPTIMUM WALL THICKNESS OF [(0.0625 X SHAFT DIA)+2.5MM]
BUSH INSIDE DIAMETER ALLOWANCE (mm)
0
100
200
300
400
500
600
700
800
900
1000
SHAFT DIAMETER (mm)

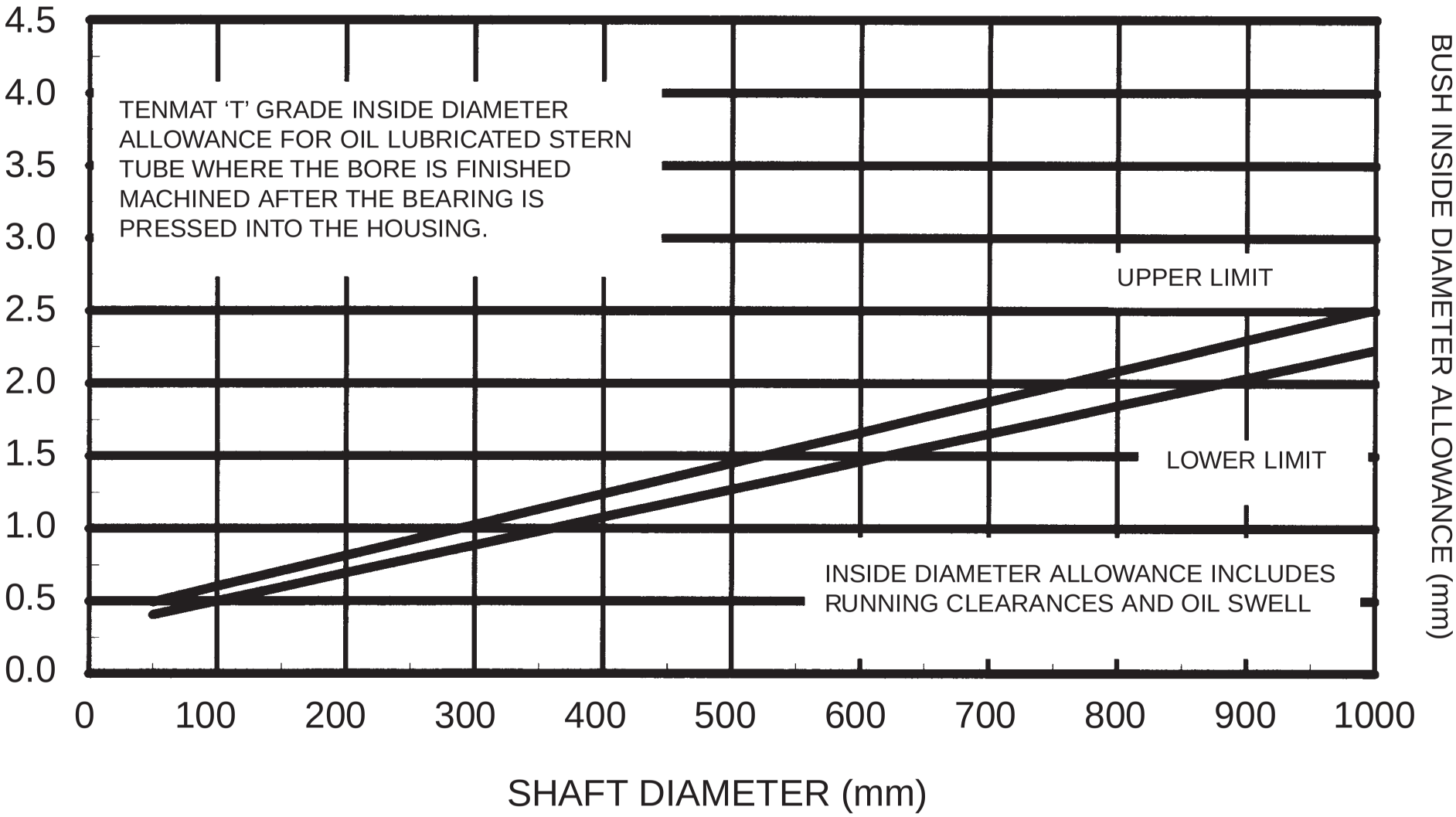
GRAPH 4


BUSH INSIDE DIAMETER ALLOWANCE (mm)
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
100
200
300
400
500
600
700
800
900
1000
SHAFT DIAMETER (mm)
UPPER LIMIT
LOWER LIMIT
INSIDE DIAMETER ALLOWANCE INCLUDES
RUNNING CLEARANCES, SWELL AND BORE CLOSURE,
BASED ON OPTIMUM WALL THICKNESS
OF [(0.0625 X SHAFT DIA)+2.5MM]
TENMAT 'T' GRADE INSIDE DIAMETER
ALLOWANCE FOR WATER AND GREASE
LUBRICATED STERN TUBE WHICH ARE
PRESSED INTO THE HOUSING WITHOUT
FURTHER MACHINING.

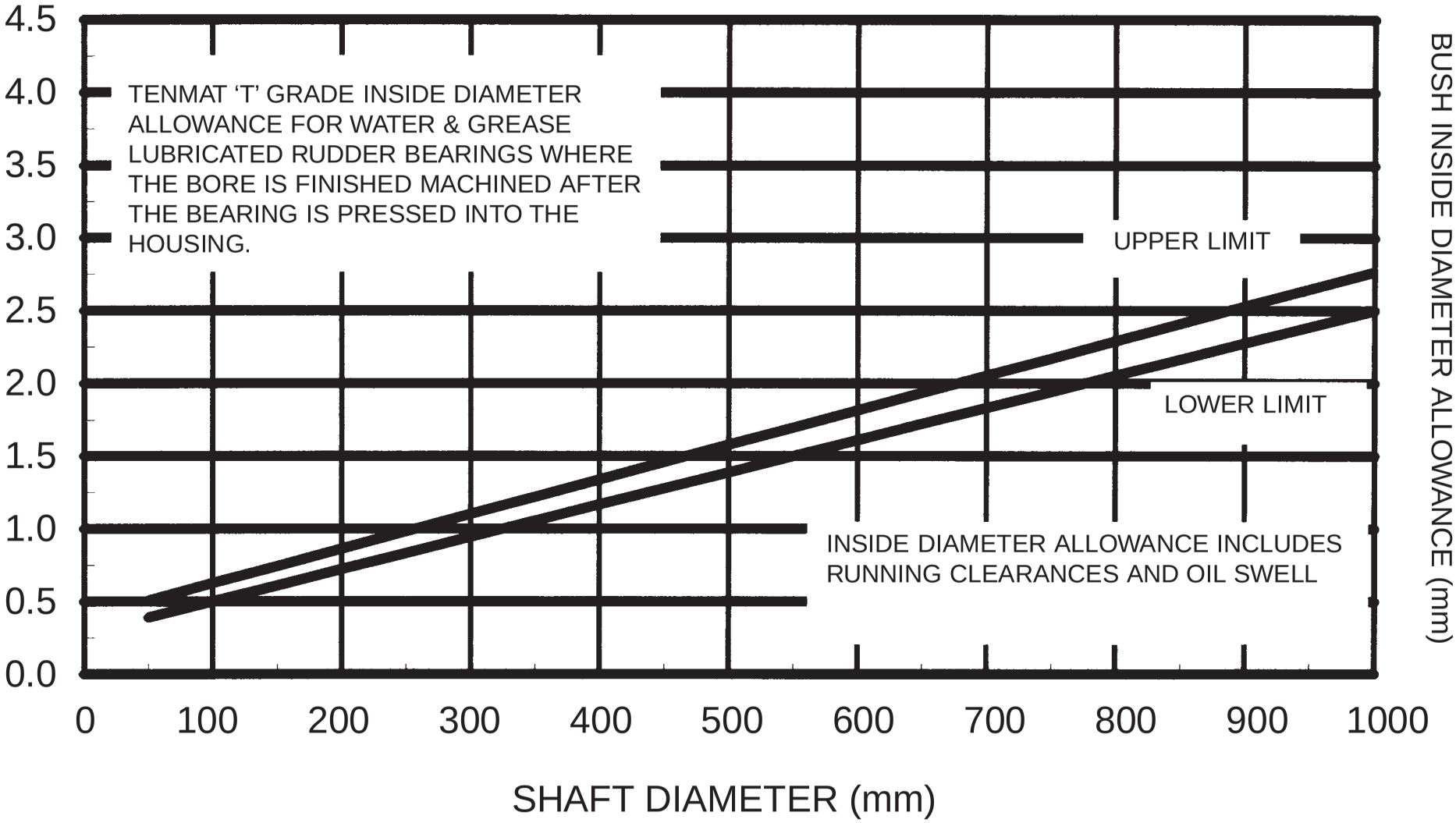
GRAPH 5


TENMAT 'T' GRADE INSIDE DIAMETER ALLOWANCE FOR WATER LUBRICATED STERN TUBE AND BRACKET BEARINGS WHERE THE BORE IS FINISHED MACHINED AFTER THE BEARING IS PRESSED INTO THE HOUSING.
UPPER LIMIT
LOWER LIMIT
INSIDE DIAMETER ALLOWANCE INCLUDES RUNNING CLEARANCES AND WATER SWELL
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
100
200
300
400
500
600
700
800
900
1000
SHAFT DIAMETER (mm)
BUSH INSIDE DIAMETER ALLOWANCE (mm)

GRAPH 6

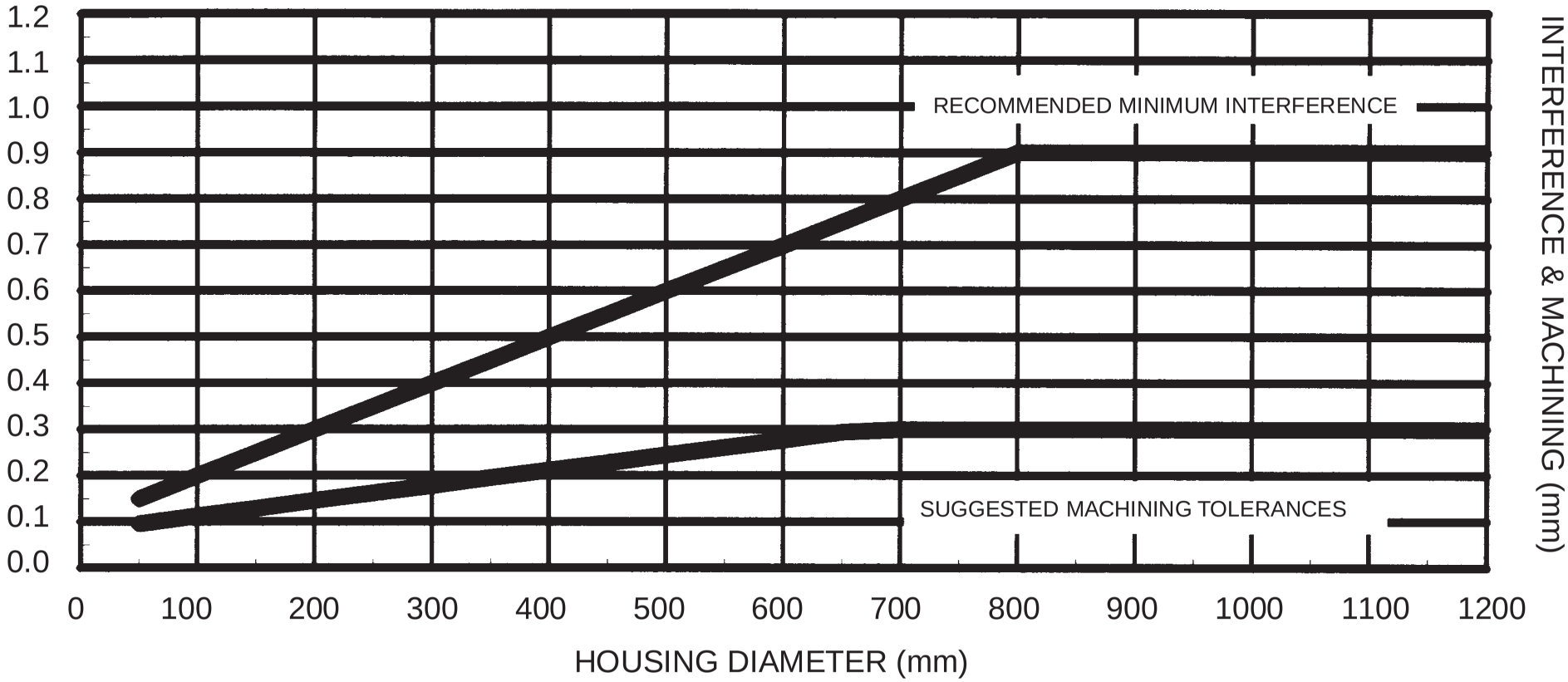

TENMAT 'T' GRADE INSIDE DIAMETER ALLOWANCE FOR OIL LUBRICATED STERN TUBE WHERE THE BORE IS FINISHED MACHINED AFTER THE BEARING IS PRESSED INTO THE HOUSING.
UPPER LIMIT
LOWER LIMIT
INSIDE DIAMETER ALLOWANCE INCLUDES RUNNING CLEARANCES AND OIL SWELL
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
100
200
300
400
500
600
700
800
900
1000
SHAFT DIAMETER (mm)
BUSH INSIDE DIAMETER ALLOWANCE (mm)

GRAPH 7


TENMAT 'T' GRADE INSIDE DIAMETER ALLOWANCE FOR WATER & GREASE LUBRICATED RUDDER BEARINGS WHERE THE BORE IS FINISHED MACHINED AFTER THE BEARING IS PRESSED INTO THE HOUSING.
UPPER LIMIT
LOWER LIMIT
INSIDE DIAMETER ALLOWANCE INCLUDES RUNNING CLEARANCES AND OIL SWELL
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
100
200
300
400
500
600
700
800
900
1000
SHAFT DIAMETER (mm)
BUSH INSIDE DIAMETER ALLOWANCE (mm)

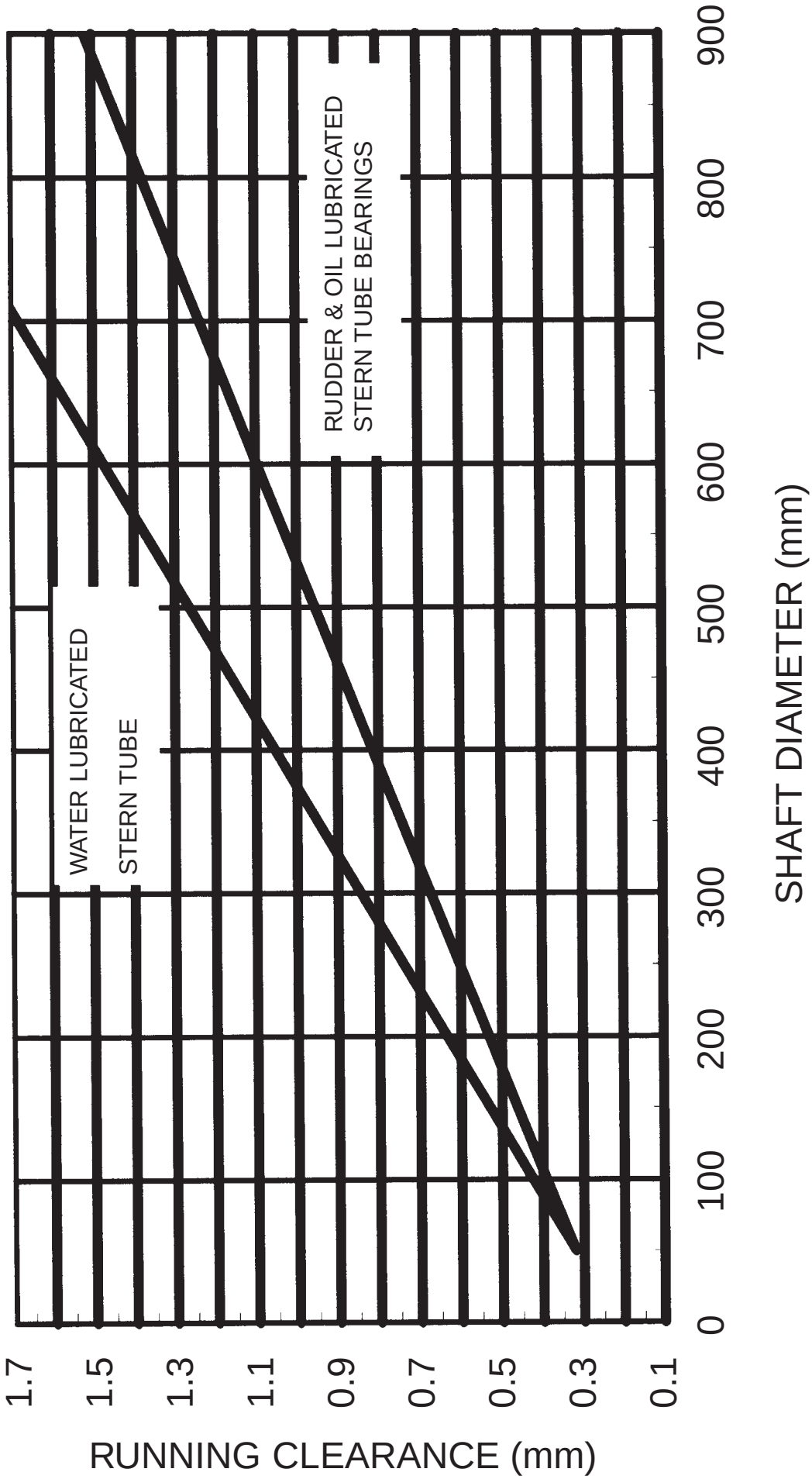
GRAPH 8

INTERFERENCE FIT AND MACHINING TOLERANCES ‘T’ GRADES ONLY



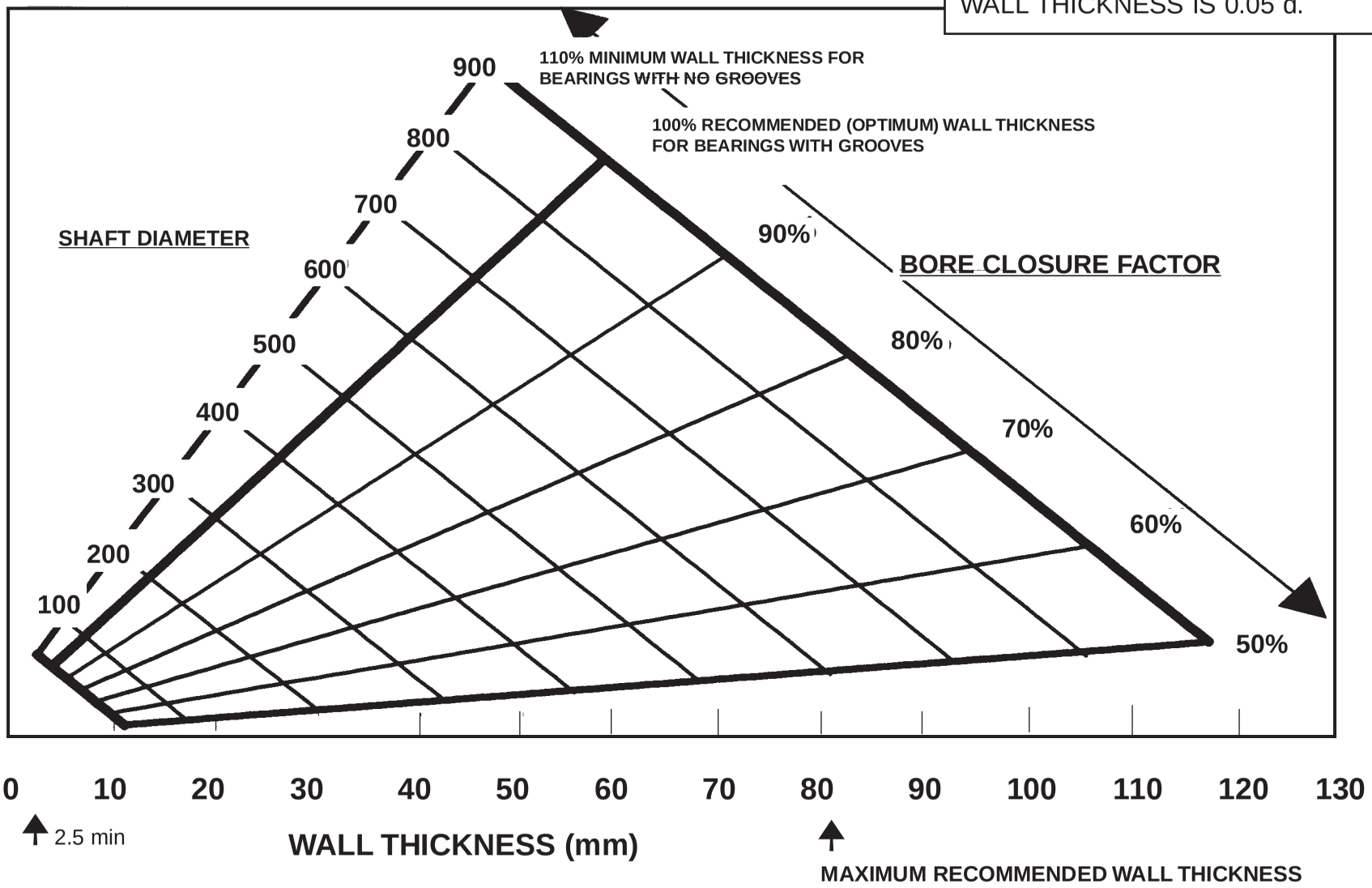
T' GRADE MARINE BEARINGS MINIMUM RECOMMENDED
OPERATIONAL RUNNING CLEARANCES

GRAPH 9



GRAPH 10

OPTIMUM WALL THICKNESS FOR BEARINGS WITH GROOVES IS 0,0625 d+2.5 mm.
FOR BEARINGS WHERE GROOVES ARE NOT REQUIRED, THE MINIMUM RECOMMENDED WALL THICKNESS IS 0.05 d.



BORE CLOSURE